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ORIGINAL ARTICLE

Changes in the salinity of the Euphrates River system in Iraq

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Abstract The water salinity of the Euphrates River as it enters Iraq, expressed as total dissolved solids (TDS), has more than doubled compared to that of 1973. Downstream of Al Hindia Barrage, south of Baghdad, the salinity has increased gradually over the last 30 years. The annual average TDS at Al Nassiriah, in the lower reaches of the Euphrates, has increased from 1,080 ppm in 1979 to more than 4,500 ppm in 2001. Water quality of the Euphrates within Iraq has deteriorated due to the decreased flow that is entering Iraq, diverted flows to the river from Al Tharthar Lake, and irrigation-return flow. The decreased flow from upstream sources was due to reservoir construction projects. Water from Al Tharthar Lake and from irrigation return flow is being diverted to the Euphrates to compensate for the upstream deficit. An environmental flow rate of 178 m^3/s (annual minimum flow, 5.6 bcm or about one-third of historic minimum flow) is proposed as the minimum discharge that must be flowing into Iraq to preserve the environment of the Euphrates River in Iraq. A flow of twice this amount would allow more reasonable downstream management with an input average salinity of 760 ppm.

Keywords Environmental flow · Euphrates River · Iraq · Minimum instream flow · Salinity

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Introduction

Increasing salinity is a problem in many major rivers in the world (FAO 1976). As salinity passes 1,000 mg/L, water becomes less useful as it is no longer potable for human consumption (WHO 1997). Above 3,000 mg/L, it is no longer suitable for most municipal or agricultural uses. Irrigation with high salinity water causes problems for most major crops (FAO 1976). Iraq depends on the Euphrates River for agriculture and municipal water supplies (Murakami 1995). As salinity increases in the river, the uses for the water must change and thus becomes limiting for supporting the local economies. Over the length of the Euphrates and over time, salinity has increased from approximately 500 ppm to over 4,500 ppm (Fattah and Abdul Baki 1980; Ministry of Irrigation 1998; Ali and Salewicz 2005). This is due to a combination of several factors that have increased salinity throughout the river system. The river ecology is severely altered and feasible measures should be implemented to restore its ecosystem as a natural river.

The main option available to mitigate the salinity of the river and to restore the ecosystem is to maintain a minimum instream flow (MIF) (also referred to as environmental flow requirements) (Partow 2001). Several authors have discussed or implemented the MIF (or environmental flow) approach (MWD and USBR 1999; Mirza 1998; Murakami 1995). The environmental flow concept "describes a fresh water flow (typically in-stream flow) that is maintained (or not allowed to be used for other, typically anthropogenic, purposes) solely for environmental reasons, to maintain the health and biodiversity of a particular water-related entity, such as a river, wetland, groundwater system or estuary. For example, water may be extracted from a particular river for a particular industry. However, an environmental flow may be maintained down the river, not diverted to this industry, to maintain downstream river and/or estuarine ecosystems by allowing natural flows to progress through the system" (Pierson et al. 2002).

Different approaches are employed to determine the MIF for a given river system (Pierson et al. 2002). The hydrological index expressed as Q_{95} is practiced in the United Kingdom (Dyson et al. 2003) as a measure of MIF. It designates the flow that is equaled or exceeded 95% of the time. In the Midwestern United States, the MIF is identified as a specific percentage of the mean annual flow: 10% for poor quality habitat (survival), 30% for moderate, and 60% for excellent habitat (Tennant 1976). A discharge-salinity correlation approach was applied for the Ganges River in Bangladesh (Mirza 1998). The approach is based on designating a salinity threshold as the criteria for the MIF. The United Nations Food and Agricultural Organization (FAO 1976) water quality guidelines recommended a 750 μmhos/cm (480 ppm) salinity level for irrigation use and for human consumption. The FAO guidelines classify a water with 750–3,000 μmhos/cm (480–1,920 ppm) as slightly to moderately restricted for irrigation use. The Iraqi Bureau for Standards set the salinity level for potable water at 1,000 ppm TDS (UNEP 2003; Arab Science and Technology Foundation 2005). The Iraqi salinity level is employed as a threshold to determine the suggested MIF rates for the Euphrates River. This article will assess the salinity of the Euphrates River; discuss the reasons of salinity increase, and present measures to manage the salinity problem.

Geography and hydrology of the Euphrates River

The Euphrates is the longest river in western Asia (Fig. 1). It originates in the Eastern Mountains of Turkey as a confluence of two streams, the Western Euphrates (the Kara Su) and the Eastern Euphrates (the Murat) (Hillel 1994; MFA and MI 1999). The Kara Su drains the high lava plateau to the northwest of Lake Van. The two streams meet at Keban where the Keban Dam is located. From there, the Euphrates flows southward through Turkey then crosses into Syria flowing southeast (Hillel 1994; Altinbilek 2004). After traveling 680 km within Syria's borders, the river flows into northwestern Iraq at Al Qaim and continues flowing to the southeast passing through and serving seven governorates and the western portion of Baghdad. The Euphrates then meets the Tigris River at Al Qurna in southern Iraq to flow into the Shat Al Arab waterway which drains into the Arabian-Persian Gulf.

The total length of the river from its origin in Turkey to Al Qurna in Iraq is 3,065 km. The total drainage basin area is 444,000 km^2. The drainage basin area is distributed over

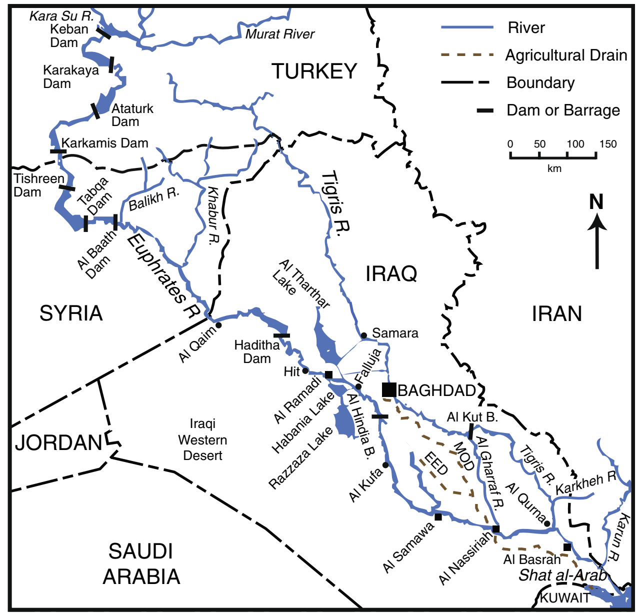

Fig. 1 Euphrates River location map

four countries, 28% in Turkey, 17% in Syria, 40% in Iraq, and 15% in Saudi Arabia (Beaumont 1978). The total annual stream flow of the upper Euphrates, across the Turkish/Syrian border, between 1937 and 1973 (prior to the construction of major dams) ranged between a minimum of 16.8 billion cubic meters (bcm) (1961) to a maximum of 53.5 bcm (1969) (Beaumont 1998; Kolars 1994). In Iraq, the average annual flow, as was recorded at the town of Hit (Fig. 1), was 33 bcm (Murakami 1995).

Currently, the flow of the Euphrates is highly regulated and controlled by a series of dams and reservoirs constructed by Turkey, Syria, and Iraq. Saudi Arabia utilizes no water from the river. In 1975, the Turkish Keban and the Syrian Tabqa dams began operation. Two years later, Turkey's Southeast Anatolia Project "Guneydogu Anadolu Projesi" (GAP) was initiated (Partow 2001). The GAP is a Turkish irrigation-agricultural project that depends on the Euphrates and the Tigris Rivers for its water supplies. The project involves, among others, the construction of 21 dams and reservoirs on the Euphrates and Tigris Rivers (Kolars 1994). Five major dams have been put in operation on the Euphrates alone (Altinbilek 2004). The storage capacity of the reservoirs bounded by these dams is more than 90 bcm, which is about two times more than the maximum recorded annual flow of the river.

The Syrian utilization project on the Euphrates involves the construction of three dams. The three dams were completed with total storage capacity of 13.7 bcm. Iraq has constructed several structures along the course of the Euphrates. Of importance for evaluating causes of salinity increase are the Haditha Dam, Habania Lake, Al Tharthar diversion project, and Al Hindia Barrage (Fig. 1). The Tharthar diversion project involves water transfer structures from the Tigris River to the Euphrates through Al Tharthar Lake. The Al Hindia Barrage plays a major role in the river water allocation among the stake holders downstream and distributes the Euphrates flow among four branches (not illustrated on Fig. 1). The largest is the main channel of the Euphrates which flows toward southern Iraq. Second, the Shatt Al-Hillah branch diverts flows toward the Babylon Governorate. The two other branches are the Musiab Canal which is used to irrigate the agricultural land of the Musiab Project, and the Hussianiah Canal which is used to irrigate the agricultural land of Karbala Governorate.

Methodology

Data for the Euphrates River are limited as the countries along the river may chose not to release or publish environmental data. Obtaining data for the study was a challenge. We relied heavily on the literature and work of the first author to acquire the necessary data for analysis. The methodology section is subdivided into two subsections—the first deals with the salinity causes and the second covers the analysis of the salinity of the river.

Salinity data sources and review

Historically, the Euphrates waters had low salinity. At the Keban gauging station, Turkey, the TDS was 261 ppm as reported by Scheumann 1993. It was classified as C2S1 (water with medium salinity and lower concentration of sodium), which is suitable for irrigation. At Al Qaim station, where the river enters Iraq (Fig. 1), the TDS was 467 ppm in 1970 (Hanna and Al Talbani 1970). The TDS at Al Samawa was about 525 ppm for the year of 1955 (The Iraqi Foundation 2003). The available spatial salinity data shows that salinity did not exceed 1,000 ppm throughout the course of the river in Iraq as of 1973 (Fig. 2). Data for Fig. 2 were extracted from the literature. The pre-1973 data were averaged from Al-Hadithi 1978 and Fattah and Abdul Baki 1980, and the post-1980 from Ali and Salewicz 2005 and the Ministry of Irrigation 1998. Ali and Salewicz 2005 published a salinity profile along the river from Al Qaim to Al Nassiriah for the water year 2000–2001. The profile shows salinity of about 1,000 ppm in Al Qaim, 1,100 ppm in Al Hindia, 3,000 ppm in Al Samawa, and 4,000 ppm in Al Nassiriah. Available temporal records of salinity at Al Falluja station (385 km from the Syrian border) show that the TDS ranged from 420 to 710 ppm during the period of 1959–1973 (Figs. 1, 3) (Al-Hadithi 1978).

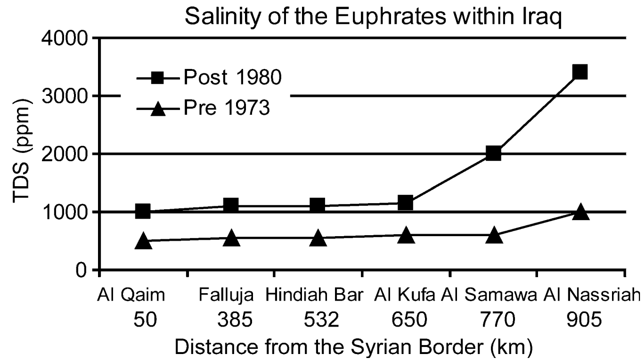

Fig. 2 Salinity along the Euphrates course prior to 1973 and after 1980 as extracted from the literature

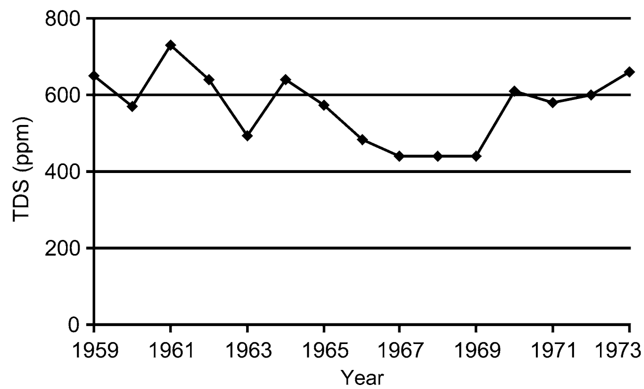

Fig. 3 Mean annual TDS at Falluja Gauging Station (data from Al-Hadithi 1978)

The river's salinity has increased gradually over the last 3 decades (Partow 2001). The first noticeable increase in salinity was recorded at the Hit station in 1975 when the filling of the upstream reservoirs (Al Tabqa and Keban) began. Fattah and Abdul Baki (1980) showed that the TDS at Hit had increased from less than 500 ppm to about 700 ppm. By 1989, the Euphrates' salinity at Al Qaim reached 1,000 ppm (Al-Najim 2003). Currently, the TDS of the river, at Al Qaim, is greater than 1,000 ppm (Fact Finding Mission 2002).

Further downstream, at Al Hindia (532 km from the Syrian border), the salinity has increased to about 1,100 ppm as measured in 2002 (Rahi 2002). Salinity values of greater than 2,000 ppm at Al Samawa and exceeded 3,500 ppm at Al Nassiriah were published for two periods (1974–1978, and 1998–2002) (Fattah and Abdul Baki 1980; Ministry of Irrigation 1998; Ali and Salewicz 2005) (Fig. 2). At Al Nassiriah, where the salinity problem is the most acute, available records show that the TDS range from 1,300 to 4,500 ppm for the years of 1979 to 2001 (Ministry of Irrigation 1998; Ali and Salewicz 2005) (Fig. 4). TDS for the years 1998–2000 are missing. Since these years were considered dry years (FAO 2003),

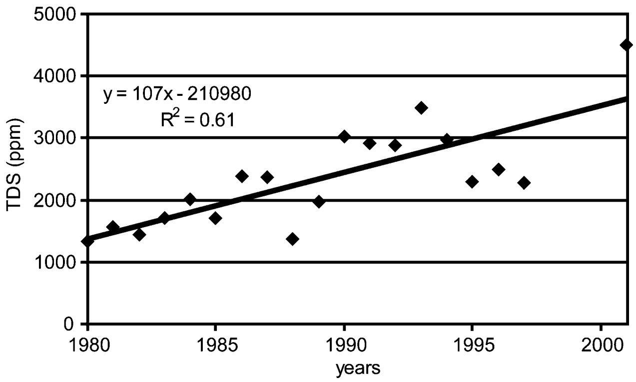

Fig. 4 Euphrates TDS contents at Al Nassiriah, Iraq

the TDS is expected to range from 3,500 to 4,500 ppm. Over this time period, the salinity increased approximately 100 ppm per year as estimated by linear regression.

The Euphrates water has degraded to a level that is not useful for any domestic or irrigation purposes starting from Al Samawa to its confluence with the Tigris at Al Qurna. Al Nassiriah relied on the Euphrates water as the main source for municipal water supply until the mid 1970s, and now depends on the Al Gharraf River (Ministry of Municipalities 1980). The Al Gharraf River branches from the Tigris River upstream from Al Kut Barrage and flows into Al Nassiriah Governorate.

Salinity analysis

Salinity data for the Euphrates' waters were analyzed to reveal the temporal and spatial salinity variations along the Euphrates in Iraq. Available data for stations along the river from its entrance, at Al Qaim, to the southernmost station of Al Nassiriah were separated into two groups, the first represents the river salinity status (1959–1973) which is designated "prior to 1973", and the second group represents the river salinity for the period from 1980 to the present. Much less salinity data were available from 1973 to 1980.

The available salinity records at the Al Fallujah monitoring station for the period of 1959 to 1973 were studied to provide a baseline for comparison with later data (post upstream dams' construction). The influence of the return irrigation inflow on the river reach downstream of Al Kufa (650 km from the Syrian border) was evaluated using the salinity data available between Al Kufa and Al Samawa. Available salinity measurements at the Al Nassiriah station were plotted against time for the period 1980–2001 to evaluate the temporal salinity trend over the lower reaches of the river.

Four possible reasons for salinity increases were investigated. These are:

1. The decreased inflow entering Iraq and the increased salinity content.
2. The flow diversion from the Tigris to the Euphrates via Al Tharthar Lake.
3. The irrigation return-flow into the river from Iraqi irrigation projects.
4. Saline groundwater intrusion from the Iraqi Western Desert (IWD).

A mixing cell model, utilizing the river discharge and the salinity data, was employed to evaluate the effect of each source.

Part of the analyses was to determine a remediation approach needed to lower salinity and preserve the river ecology. Maintaining a minimal discharge as MIF through out the river course in Iraq is needed to preserve the river environment. The MIF is calculated using the salinity threshold used by Mirza 1998. The data used for the analyses are the salinity time series at the Falluja Station for dry, average, and wet years.

Results

The influence of each of the salinity sources listed above is evaluated in the following subsections. Flow of the Euphrates as well as salinity load is analyzed in order to estimate the contribution to the salinity from each source. Discharge-salinity correlations, as bases of the MIF calculations, are detailed at the end of this section.

Reasons of salinity increase

The four possible reasons of increasing the Euphrates River's salinity are analyzed and discussed below. The analyses are conducted in downstream order.

Decrease of inflow

As of 1997, the total storage value of all the dams that had been constructed on the Euphrates in Turkey was 90.9 bcm and it will reach 94.78 when all of the GAP works completed. This storage capacity is about three times the 30.7 bcm average annual river's flow (Partow 2001). In Iraq and Syria, the combined storage capacity of all dams was 22.88 bcm. Adding this figure to the Turkish reservoirs capacity makes the gross storage capacity of all existing hydraulic structures on the Euphrates 117.66 bcm. This storage capacity is about four times the river's average annual flow (Partow 2001).

A protocol was signed between Turkey and Syria in 1987 to assure a continuous minimum flow of 500 m^3/s in the Euphrates as it enters Syria. The salinity of the released water was unfortunately not specified (Beaumont 1996).

The water released from Turkey is largely irrigation return flow (Partow 2001; Topkaya 1998). Bilen (1997) estimated the TDS of the return flow to be 700 ppm. However, data from the adjacent Seyhan River basin show that the return flow salinity is 1,025 ppm, while that of the original irrigation water was 225 ppm (Scheumann 1993). This means that an approximately four fold increase in salinity is expected for the return flow within Turkey. If this is the case, and since the salinity of the Euphrates at Turkey was 261 ppm (Scheumann 1993), then the return flow should be approximately 1,040 ppm TDS.

According to the 1990 protocol (between Syria and Iraq), Iraq is to receive 58% of the Euphrates flow that enters Syria or about 9.2 bcm per year. This flow includes components from the main stream Euphrates through the Tabqa Dam as well as flow from the Balikh and Khabur Rivers. The flow component that is expected from the Tabqa Dam is about 6.8 bcm/year and of salinity of 1,040 ppm. From the Khabur River the annual release is approximately 1.4 bcm/year with a similar salinity as the Euphrates. The portion released to Iraq from the Balikh River is 1 bcm/year at 2,000 ppm salinity.

A salinity mass balance can be completed using the following linear equation:

$$\mathrm{TDS_{in}} = \frac{Q_{\mathrm{Euph}} \times \mathrm{TDS_{Euph}} + Q_{\mathrm{Bal}} \times \mathrm{TDS_{Bal}} + Q_{\mathrm{Khab}} \times \mathrm{TDS_{Khab}}}{Q_{\mathrm{Total}}} \quad (1)$$

where Q is discharge (m^3/s), $\mathrm{TDS_{in}}$ is the total dissolved solids entering Iraq (ppm); and Q_{Total} is the total Euphrates inflow into Iraq. Using the above data in Eq. 1, the predicted TDS of the Euphrates as it enters Iraq is 1,100 ppm when all the upstream irrigation schemes are included. Kolars (1994) estimated the river flow into Iraq will be 6.6 bcm after the completion of the GAP scheme all of which contains irrigation return flow but has no given salinity figure. It is reasonable to assume the salinity of irrigation return flow to be approximately 1,100 ppm.

Flow diversion from Al Tharthar Lake to the Euphrates

By the late 1970s, Iraq started to divert water from the Tigris to the Euphrates through Al Tharthar Lake. Al Tharthar water is of high salinity even when compared to the present day Euphrates water. Studies show that the current TDS of the lake is about 1,500 ppm, while that of Euphrates at Habania Lake is about 1,000–1,100 ppm (The Iraqi Foundation 2003). Several studies cautioned against the diversion of Al Tharthar waters to the Euphrates due to the high salinity of Al Tharthar Lake (Beaumont 1998; United Nations 1997).

To quantify the effects of the diverted Al Tharthar Lake water on the salinity of the Euphrates, a mass balance analysis (similar to Eq. 1) was performed. Total inflow entering Iraq is 290 m^3/s. Iraq consumptive use from the Euphrates, as estimated by Altinbilek (2004, Table 5) ranges from 13 to 19 bcm/year or about 512 m^3/s. Therefore, Iraq needs to divert 222 m^3/s from the Al Tharthar Lake to the Euphrates. The salinity of Al Tharthar water is 1,500 ppm. The total flow of the Euphrates at the Al Tharthar discharge point is 190 m^3/s (100 m^3/s is either consumed or lost by evaporation upstream from this point). Based on these figures, the estimated TDS of the Euphrates water, after being recharged from Al Tharthar Lake, is approximately 1,320 ppm.

Irrigation return flow within Iraq

Downstream from the city of Al Kufa, the Euphrates is, literally, used as a drain carrying the irrigation return from several agricultural areas (Grego et al. 2004). Fattah and Abdul Baki (1980) studied the effect of drainage water on the Euphrates water quality. Their study concluded “the influence of agricultural drainage disposal on the quality of the Euphrates River water between Al Hindia and Al Shinafiya (a town located on the river just upstream from Al Samawa) is remarkably significant and may explain the major portion of the increase in concentration of TDS along that reach.” In another portion of their paper, the authors stated that the major portion of the increase in concentration of TDS between Hit and Al Nassiriah occurs between Al Hindia and Al Shinafiya with a second major increase in concentration between Al Shinafiya and Al Samawa.

During 2002, the Iraqi Ministry of Irrigation (MI) measured the river’s TDS for the reach that extends from Al Kufa to Al Nassiriah. The analysis showed that the TDS was 1,100 ppm near Al Kufa, increased to 4,000 ppm at Al Samawa, and attained 5,000 ppm at Al Nassiriah (Fig. 5) (Rahi 2002). The river reach between Al Kufa and Al Samawa receives irrigation return flow from at least four agricultural drains. These drains are:

1. Al-Jarrah Al-Sharqiah Drain (Flow = 15 m^3/s, and TDS = 2,065 ppm)
2. Al-Jarrah Al-Gharbiah Drain (Flow = 12 m^3/s, and TDS = 4,225 ppm)
3. Al-Khassaf Drain (Flow = 18 m^3/s, and TDS = 4,000 ppm)
4. Nagarat Abo Hijar Drain (Flow = 21 m^3/s, and TDS = 4,262 ppm)

Irrigation return flow constitutes about 70% of the stream flow at this reach of the Euphrates. A mixing model was used to estimate the increase in salinity caused by the return flows in the reach (Fig. 6). The computed estimated TDS was 2,784 ppm which is 25% higher than the

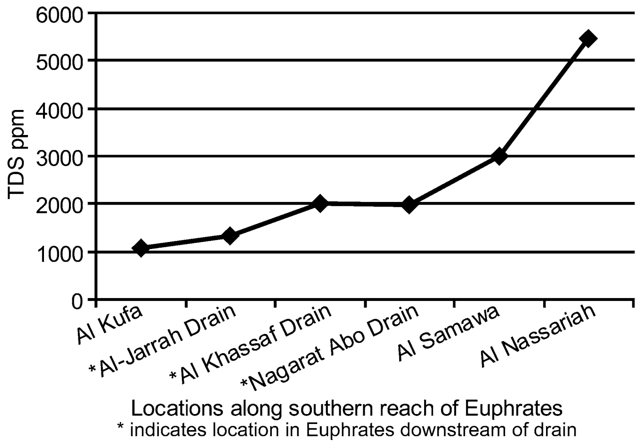

Fig. 5 TDS in the Euphrates in 2002

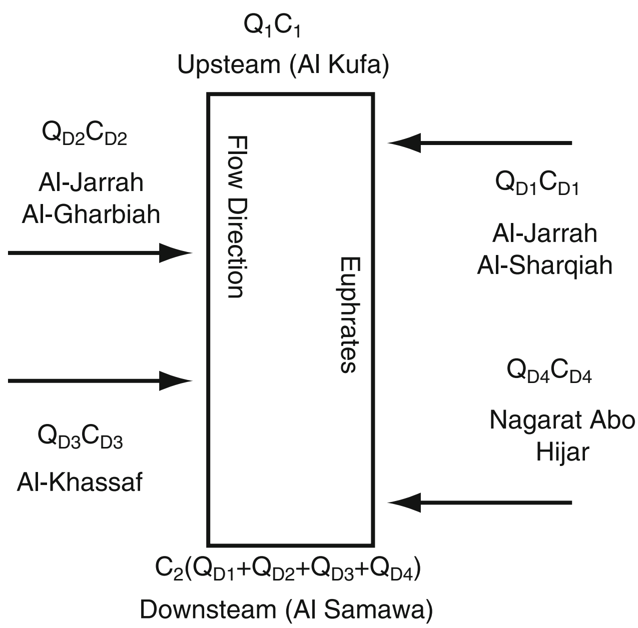

Fig. 6 Schematic representations for the drainage water flow into the Euphrates between Al Kufa and Al Samawa

measured value downstream of Nagarat Abo Hijar Drain shown in Fig. 5.

Groundwater discharge

The Euphrates River in Iraq may be a gaining stream with hydraulic connections to the highly saline groundwater that flows from the aquifers of the Iraqi Western Desert (IWD). The increase in the salinity of the Euphrates between Al Samawa and Al Nassiriah may be caused by the saline groundwater intrusion from the IWD (USAID 2004). No irrigation return flow is known to be diverted to the river, yet the salinity increases significantly in this reach.

In 2002, the Iraqi Ministry of Irrigation conducted hydrogeological investigations at two sites along the Euphrates between Shinafiya and Al Samawa (Ministry of Irrigation 2002). The groundwater investigation did not include the river reach between Al Samawa and Al Nassiriah. The data collected during these investigations were later analyzed to assess the interaction between the river and groundwater (Rahi 2002). These two studies provided significant information on groundwater/surface water interactions along this reach. Two aquifers were identified: an upper unconfined shallow aquifer, and a lower confined aquifer. The upper unconfined aquifer discharges to the Euphrates River. No interaction could be found between the confined aquifer and the river. The TDS contents of groundwater ranges from 4,400 to 9,000 ppm. The unconfined aquifer analysis showed a large temporal and spatial variation in the TDS (Rahi 2002).

Based upon these two studies, a hydraulic connection exists between the Euphrates and the unconfined aquifer. However, this aquifer is shallow and local and could not be linked to the IWD. As a shallow aquifer, its recharge source is most likely local irrigation water. The hydraulic conductivity is estimated to be 10 m/day. The local groundwater gradient is about 0.01 m/m. The estimated flow rate is approximately 0.007 m^3/s per km of the river course. At this flow rate groundwater would not constitute a major pollution source. This study concluded that the effect on the river water quality that may be attributed to groundwater is minor and would not be linked to the saline groundwater that flows from the IWD.

Downstream of Al Samawa, the significant increase of the salinity for the reach that extends to Al Nassiriah (Fig. 6) could not be explained based on the findings of these studies. Two other possible causes may contribute to it. A link between the confined aquifer of the IWD and the river may exist along the reach through which large volumes of saline groundwater are recharging the Euphrates. The other possibility is that the salinity comes from the dissolution of evaporative formations that are dominant in the area (The Iraqi Foundation 2003). Further studies are needed to test these two hypotheses.

Discharge–salinity correlations

The mean monthly flows at Hit Measuring Station were incorporated with the mean monthly TDS measured at the Falluja Station for the years 1961, 1965, and 1969. These years are dry, average, and wet respectively (Al-Hadithi 1978). The recorded stream flows reflect the natural state of the river prior to large-scale upstream development. A regression model is fit to the data and is shown in Fig. 7. A power law relationship gives the regression equation for salinity is given by:

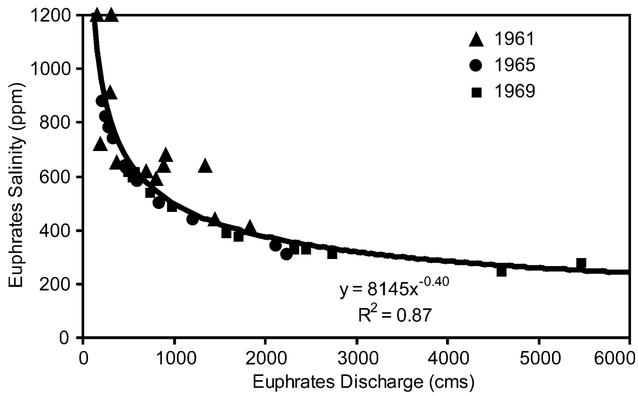

Fig. 7 The salinity of the Euphrates River for given values of discharge at Hit

$$S = 8,145 \times Q^{-0.4045} \quad (2)$$

where S is the salinity reflected by TDS (ppm) and Q is the discharge (m^3/s). The coefficient of determination, R^2 for this equation is 0.87. This model generates a value for the MIF discharge (Q) equal to 178 m^3/s, which results in a salinity of 1,001 ppm. A discharge of twice that amount would yield a salinity of 757 ppm.

Salinity management options

Three salinity management options are reasonable to reduce or reverse the mechanisms of increasing salinity in the Euphrates. First, maintain a MIF of 178 m^3/s throughout the course of the river. The other management options are to cease the release of water from Al Tharthar Lake, and to divert the irrigation return discharge away from the river. The measures could be implemented without extreme difficulties, but require the mutual collaboration of the riparian countries.

The United Nation Environmental Program (Partow 2001) indicated that adherence to the policy guidelines established by the World Commission on Dams (2000) should considerably reduce their negative impact. The UNEP recommended that the compliance with international treaties, particularly the United Nations Convention on the Law of the Nonnavigational Uses of International Watercourses (United Nations 1997) before commissioning a dam project. For the Euphrates, a sound water resources management plan can implemented only through the collaboration of the three riparian states.

Minimum instream flow

The calculated MIF rate using Eq. 2 is 178 m^3/s (Fig. 7), which is approximately one-third of the historical flow into Iraq. This flow should be maintained at all times within the river course to improve the water quality and preserve the environment of the Euphrates. Kolars (1994) estimated a flow rate of 160 m^3/s as the "necessary flow to the Gulf to maintain gravity flow irrigation, surge capacity and basic riverine ecology". Ubell (1971) suggested a minimum flow of 292 m^3/s to be maintained in Shat Al Arab "to preserve its natural ecosystem, to transport agricultural and industrial wastes, and to prevent seawater intrusion". The TDS of the Euphrates MIF as it enters Iraq at Al Qaim could be kept similar to historical conditions if the upstream users could find other disposal mechanisms for irrigation return flow. Topkaya (1998) has suggested mixing the return flow with the fresh water of the reservoirs to dilute the high content of salinity. At the 178 m^3/s level, the Euphrates salinity wouldn't increase above 1,000 ppm over the course of the river.

Control the release from Al Tharthar Lake

In 1995, Turkey started to transfer 330 m^3/s from the Euphrates to irrigate an area located within the Tigris basin via the Urfa Tunnel (Beaumont 1998; Al-Najim 2003). Iraq, in turn, compensated for these waters by diverting part of the lower quality waters of Al Tharthar Lake to the Euphrates. It should be mentioned that Turkey and Syria consider the Euphrates and the Tigris to have one drainage basin (watershed), not two separate ones. Therefore, they do not consider this water transfer as a trans-basin water transfer. Iraq considers the two rivers to have two naturally separated and well-defined basins and view this water transfer as trans-basin allocation. For Iraq, the drainage basin that is referred to as the Euphrates–Tigris basin is in fact the Shat al-Arab Drainage Basin (MFA and MI 1999). The Shat al-Arab Drainage Basin includes, along with the Euphrates and the Tigris, the Karkheh and the Karun Rivers. The Karkheh River originates in Iran and joins the Tigris just upstream of Al Qurna. Further downstream, the Karun River flows into Shat al-Arab from the Iranian Territories. Regardless of the above geopolitics, if the concept of MIF is employed on the Euphrates, no flow should need to be diverted from Al Tharthar Lake to the Euphrates. This would require the three riparian countries to engage in integrated trans-basin water management schemes that minimize the salinization process of both the Tigris and the Euphrates.

Diversion of the Iraqi irrigation return flows to the Eastern Euphrates drain

The Euphrates is utilized as agricultural drain on its lower reaches. Iraq, faced with reduced discharges from upstream has intensively control the Euphrates downstream from

Al Hindia Barrage. Therefore, most of the river flow downstream of Al Kufa comes from the irrigation return flow. Measures need to be taken to limit this practice. Irrigation return flow needs to be diverted from the river system to the already established Iraqi irrigation drainage system. The diversion could be accomplished through the implementation of the Eastern Euphrates Drain (EED), located east of the Euphrates (Fig. 1). The EED is an integrated part of the Iraqi Agricultural Drainage Network. It originates at a point east of Al Kufa, runs southward parallel to the Euphrates for 177 km, and turns eastward for 88 km where it flows into the Tigris-Euphrates Main Outfall Drain (MOD) (Fig. 1). The MOD then carries the drainage water to the Gulf. The total length of the EED is 261 km. The Iraqi Ministry of Water Resources assumed the implementation of the EED, but the work is not yet complete. The impacts of the drain project would need to be monitored if implemented.

Summary and conclusions

The salinity of the Euphrates in Iraq has increased due to (1) the decrease in quantity and the increase in salinity of the flow that is entering the country, (2) the recharge to the river from Al Tharthar Lake, and (3) irrigation return flows within Iraq. The salinity at the lower reaches of the river have increased to a point at which the river water is no longer useful for most municipal or agricultural purposes.

The concept of MIF (or environmental flow) is suggested as a measure to improve the water quality and preserve the environment of the river. An environmental flow rate of 178 m^3/s is calculated as the minimum flow that must be sustained to improve the water quality and to preserve the environment of the Euphrates. This flow must be maintained from Al Qaim to Al Qurna where the Euphrates meets the Tigris. A flow of twice this amount would allow some minimum flexibility in managing salinity downstream from the border.

The TDS of the MIF as it enters Iraq at Al Qaim could be improved by managing irrigation return flow upstream of Iraq. Furthermore, eliminating the diversion of water to the Euphrates from Al Tharthar Lake will decrease the salinity of the Euphrates, but this quantity of water would need to be replaced at the Syrian border. Diverting the irrigation return flow from the river system to the Euphrates–Tigris Main Outfall Drain system could improve the salinity, but further study is required to access the impacts in the lower reaches of the river.

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